ICESat Antarctic elevation data: Preliminary precision and accuracy assessment

C. A. Shuman,[1] H. J. Zwally,[1] B. E. Schutz,[2] A. C. Brenner,[3] J. P. DiMarzio,[4] V. P. Suchdeo,[5] and H. A. Fricker[6]

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[1] Since 'first light' on February 20th, 2003, NASA's Ice, Cloud, and land Elevation Satellite (ICESat) has derived surface elevations from ~86°N to 86°S latitude. These unique altimetry data have been acquired in a series of observation periods in repeated track patterns using all three Geoscience Laser Altimeter System (GLAS) lasers. Here, we focus on Antarctic ice sheet elevation data that were obtained in 2003–2004. We present preliminary precision and accuracy assessments of selected elevation data, and discuss factors impacting elevation change detection. We show that for low slope and clear sky conditions, the precision of GLA12 Laser 2a, Release 21 data is ~2.1 cm and the relative accuracy of ICESat elevations is ±14 cm based on crossover differences. **Citation:** Shuman, C. A., H. J. Zwally, B. E. Schutz, A. C. Brenner, J. P. DiMarzio, V. P. Suchdeo, and H. A. Fricker (2006), ICESat Antarctic elevation data: Preliminary precision and accuracy assessment, *Geophys. Res. Lett.*, *33*, L07501, doi:10.1029/2005GL025227.

1. Introduction

[2] The primary objective of ICESat is to provide consistent, repeated surface elevations of Antarctica and Greenland, thereby enabling precise change detection and improved mass balance assessments over the mission lifetime [*Zwally et al.*, 2002]. Technical issues with the lasers have reduced data acquisition from a planned continuous mode to discrete operation periods [*Abshire et al.*, 2005; *Schutz et al.*, 2005]. These problems also caused a reduction in the planned spatial coverage. Despite this, ICESat has provided extensive, detailed ice sheet elevation data with excellent precision and accuracy statistics. Here we illustrate both the quality of the data and suggest some of the challenges to achieving improved data in the future. This paper will focus on Antarctic data to manage its scope but these results generally pertain to Greenland and other large ice masses.

[1]Cryospheric Sciences Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[2]Center for Space Research, University of Texas, Austin, Texas, USA.
[3]SSAI, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[4]SGT Inc., NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[5]NVI Inc., NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[6]Scripps Institution of Oceanography, University of California, San Diego, California, USA.

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[3] Elevations from the GLA12 Antarctic and Greenland Ice Sheet Data Product from the first three operations periods (Laser 1, Laser 2a, and Laser 2b) are shown in Figure 1. These initial periods had different spatial and temporal characteristics; subsequent operations to date are all spatially similar to the Laser 2b coverage (Figure 1c). The GLA12 elevations were derived using the "standard fit", where each value corresponds to the centroid of a Gaussian fit to a return pulse [*Brenner et al.*, 2003]. During Laser 1, ICESat operated in an 8-day repeat orbit; this provided ~5 passes along each track during a ~38 day period (Figure 1a). This track pattern was initially continued for ~9 days in the Laser 2a period; it was then followed by ~46 days of a 91-day repeat pattern (Figure 1b). The Laser 2b period and subsequent periods have repeated the last ~33 days of the Laser 2a observations [see *Schutz et al.*, 2005, Table 1]. Laser 2a's greater spatial coverage is clearly seen in Figure 1b; specific geographic references used in this paper are shown in Figure 1a.

[4] Close examination of these track maps shows the effects of clouds that can cause irregular gaps in the elevation profiles. This effect is most severe over the ocean but also has a significant impact on parts of West Antarctica (Figure 1c [see *Spinhirne et al.*, 2005]). Despite clouds, the amount of altimetry data acquired by ICESat is large; GLAS emits >350,000 shots over Antarctica each operational day and receives a surface return from >80% of the pulses; this value can vary from ~77 to 86%. By comparison of repeat tracks and 'crossovers', ICESat data can enable ice sheet change detection [e.g., *Smith et al.*, 2005].

2. ICESat Precision and Relative Accuracy

[5] We examine the ICESat data in two ways. First, we use repeat track data from Laser 2a (Release 21) and Laser 3a (Release 23) to illustrate precision and to show some of the challenges of using the data for elevation change detection. Second, we perform a crossover analysis of Laser 2a elevations to assess their 'relative accuracy'. Crossover residuals provide a relative measure of accuracy since the elevations are being compared to themselves, not to an independently defined reference surface [e.g., *Fricker et al.*, 2005].

2.1. Precision and Repeat Track Analyses

[6] This repeat-track analysis illustrates both ICESat's precision and its ability to closely remeasure a specific topographic profile. We chose data across Lake Vostok in East Antarctica (see Figure 1a) because of this area's low slope and accumulation [*Studinger et al.*, 2003]. ICESat Track 0071 crosses ~235 km of this feature and was

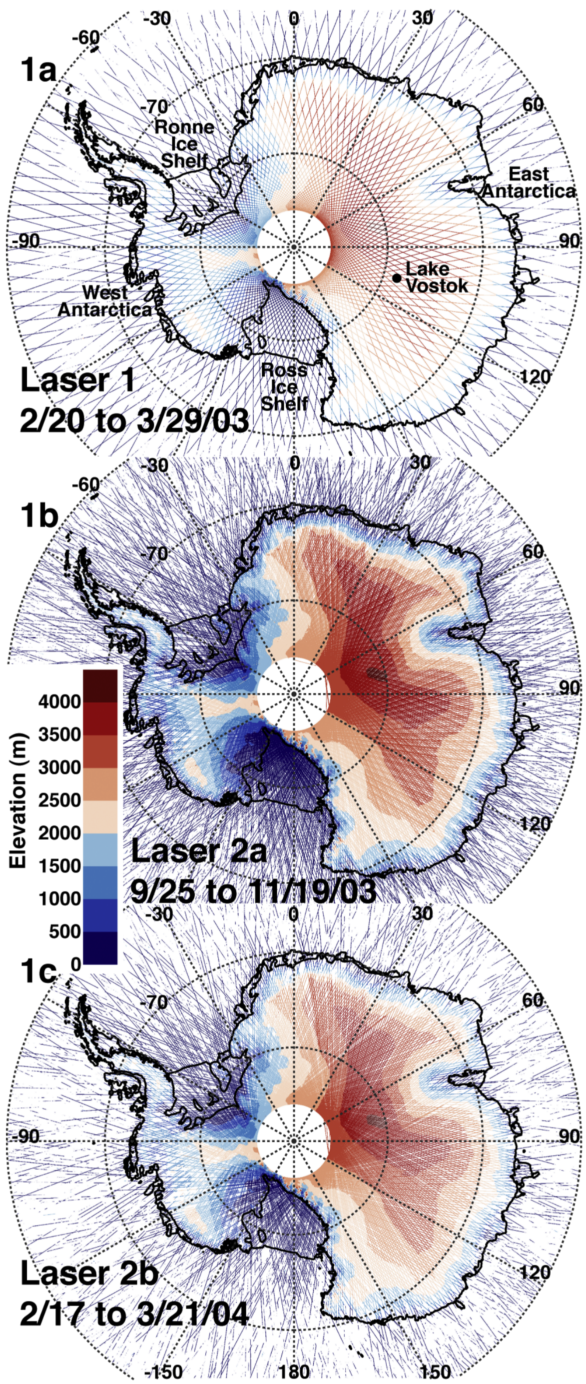

Figure 1. Coverage maps of ICESat's Laser (a) 1, (b) 2a, and (c) 2b operation periods over Antarctica. Irregular gaps in the coverage indicate the presence of clouds that prevented elevation determination.

acquired on 10/26/03 (Laser 2a) and on 10/14/04 (Laser 3a). The surface's gentle slope is shown in Figure 2a; the elevation rises only ~30 m across the area. Ancillary data indicate that both profiles were obtained through clear skies so the potential atmospheric impact is small. However, GLAS detector saturation affects these data [*Abshire et al.*, 2005] and this leads to elevations that are 10s of cm too low. Correction is currently possible over low slopes [*Sun et al.*, 2004; *Fricker et al.*, 2005] and the average correction for the Laser 2a profile was ~32 cm with a standard deviation (SD) of ~4.9 cm. The corresponding values for the Laser 3a data were ~27 and 5.7 cm, respectively.

[7] We estimate ICESat's precision for both repeats by calculating the shot-to-shot variability in the saturation-corrected GLA12 elevation profiles relative to a 9-point (~1.5 km) running mean. We then differenced the original from the mean elevation profile (Figure 2a). The difference values are usually below 5 cm for both profiles and the ~1100 individual differences show a SD of ~2.1 and ~2.3 cm for Laser 2a and Laser 3a, respectively. This shot-to-shot precision exceeds the expected value of 10 cm per pulse for ice sheet interiors [*Zwally et al.*, 2002].

[8] In order to evaluate any elevation change over the ~1 year period, we compared the Laser 2a and 3a repeats of Track 0071 (Figure 2b). We determined the horizontal and vertical separation between the two profiles by aligning them to minimize the distance between the individual measurement points, and then calculated each separation. Because of orbital variations, the tracks are not parallel and the cross-track distance varies from ~25 m to ~85 m in this case. Also note the ~1 Hz oscillation of the cross-track distance between the two profiles as discussed by *Schutz et al.* [2005]. The Laser 2a elevations are generally higher than those from Laser 3a, and this difference varies over ~35 cm range (Figure 2b). Since the tracks do not repeat exactly, a small part of these differences is from cross-track slope. Using a cross-track slope derived from other ICESat data, this factor contributes up to 1.5 cm, which is much smaller than the derived elevation difference signal. It is unlikely that the magnitude of the surface elevation change at Vostok over one year is as high as these results suggest, nor that any real change has this spatial variability. We conclude that the ICESat data currently contain small but perceptible geolocation and other possible errors and therefore cannot yet be used to determine elevation changes at this level. See further discussion given by *Luthcke et al.* [2005] and in the text below.

4. Summary

[14] This paper introduces the ICESat elevation data for Antarctica and quantifies its current precision and relative accuracy. Based on the Laser 2a period, these results document ICESat's ability to assess the Antarctic ice sheet's surface elevations and suggest the magnitude of its minimum change detection ability. In the near future, each operations period through the mission lifetime will be similarly characterized. Discerning elevation change with time is clearly possible but some limitations inherent to the data must be considered especially if the signal is at the few decimeter level or below. Given the excellent precision and accuracy possible from ICESat, for most glaciological studies the main limitation for studying specific areas may be availability of data due to reduced spatial or temporal coverage, and/or cloud cover. ICESat data are currently enabling definition of ice sheet topography with a resolution not available from other existing satellite instruments.